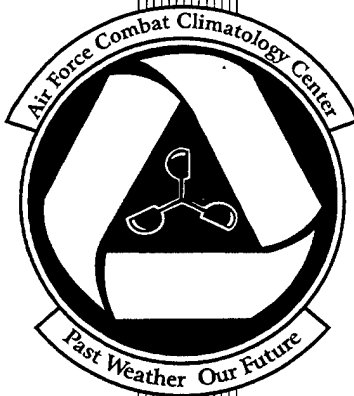


AFCCC/TN-96/008



Lightning Climatology for Nellis AFB, Nevada

By
William R. Schaub, Jr.



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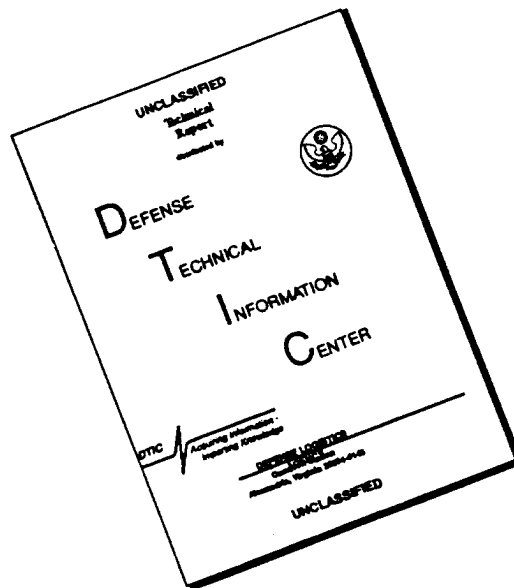
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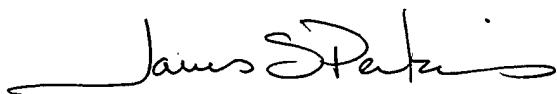
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PREFACE

This technical note documents the results of AFCCC (formerly USAFETAC) Project 921216. The project analysts were Mr. William R. Schaub, Jr. and Capt Christopher A. Donahue.

The customer, the 57th Operations Support Squadron (Weather Flight), at Nellis AFB, Nevada, requested a lightning climatology for a large area around Nellis AFB to provide an extra data source to improve their forecasts over the area. Of particular interest were the local flying area and the Nellis Ranges. A climatology of cloud-to-ground lightning strikes was developed for the Nellis AFB area from a database of lightning strikes that occurred from March through October during 1986-91. Upper-air reporting stations in the area were used to stratify the lightning-strike observations by nine 700-mb wind direction categories including calm. The area was divided into grid boxes 10 minutes of latitude by 10 minutes of longitude to provide a horizontal resolution of about 10 nautical miles. Lightning-strike observations for each grid box were summarized to obtain the average hourly lightning strikes for each 700-mb wind direction category by month.

The summarized lightning data was used to produce a microcomputer graphics program that enables the user to display the lightning-strike climatology in graphs, tables, and isopleth analyses. One graph shows the average hourly lightning strikes by 700-mb wind direction category for any combination of grid boxes, months, and hours. Another graph shows the diurnal variation in the average hourly lightning strikes for any combination of grid boxes, months, and 700-mb wind direction categories. A third graph, based on one upper-air station representative of the entire area, shows the annual average number of occurrences and percent occurrence frequencies of 700-mb wind direction categories for either 0000Z or 1200Z for any combination of months. A table option shows average hourly strikes for each 700 mb wind direction category and all categories, and for each month and all months, for any combination of grid boxes and hours. Isopleth analyses of the average hourly lightning strikes over the entire area are also available for any combination of months, hours, and 700-mb wind direction categories.

Analysis of the lightning climatology showed that the patterns of lightning strikes compared favorably with known preferred locations and times of thunderstorms in southern Nevada and neighboring states. AFCCC recommends use of the lightning climatology as another tool for mission planning and weather forecasting.

The author is grateful to Maj Lauraleen O'Connor for her review and comments. He also appreciates the fine work by Capt Christopher A. Donahue who summarized the data. Special thanks to MSgt Robert G. Pena and Amn Kenneth G. Weston who produced the lightning graphics program.

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Chapter 1

INTRODUCTION

1.1 Background. The 57th Operations Support Squadron Weather Flight (57 OSS/OSW) at Nellis AFB, Nev., provides weather forecasts for military flying missions over a large area that includes southern Nevada and parts of the neighboring states of Utah, Arizona, and California. Thunderstorms pose a threat to aviation in that area, especially from June through August during the southwest monsoon. To enhance their forecast support to flying missions and Nellis Range activities, the 57th OSS/OSW requested a

personal computer-based cloud-to-ground (CG) lightning-strike climatology, stratified by 700-mb wind direction categories, for the analysis area shown in Figure 1. AFCCC used a 6-year (1986-91) database of lightning-strike observations and upper-air observations to develop the lightning climatology for March through December. An interactive microcomputer graphics program was produced to display the climatology in graphs, tables, and isopleth analyses.

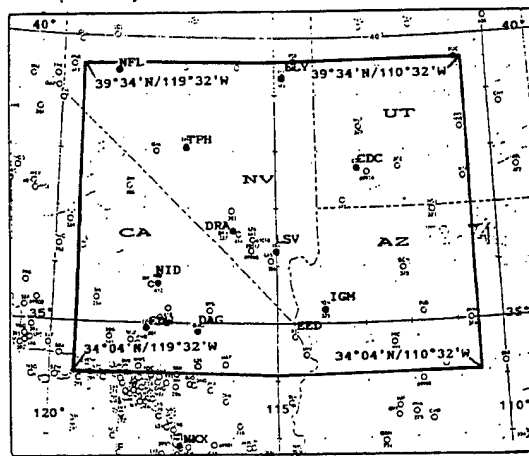


Figure 1. The area of interest. Analysis area is in bold lines. Labeled stations are: China Lake Naval Air Field (NID), Edwards AFB (EDW), Barstow-Daggett (DAG), Needles (EED), and San Diego (NKX) in Calif.; Fallon Naval Air Station (NFL), Ely (ELY), Tonopah (TPH), Desert Rock (DRA), and Nellis AFB (LSV) in Nev.; Cedar City (CDC) in Utah; and Kingman (IGM) in Ariz.

1.2 Related Studies. For many years, weather forecasters at Nellis AFB have studied the patterns of thunderstorm development and movement in that area. As described in early forecasting studies, the topography of the area is basin and range with the ranges oriented generally north-south. Elevations vary from less than 2,000 feet MSL (mean sea level) to more than 10,000 feet MSL. Nellis AFB, at a field elevation of 1,878 feet MSL, is in a broad valley almost completely surrounded by mountains: the Spring Mountains are 20 to 30 miles west with mean elevations of about 8,000 feet MSL; the Sheep Mountains are 50 to 60 miles northwest, and the Las Vegas Mountains are 10 miles north, with mean elevations of 7,000 to 8,000 feet MSL; and the Muddy Mountains are 15 to 20 miles east with mean

elevations of about 6,000 feet MSL. A local Forecast Study (1954) for Nellis AFB noted that most thunderstorms occur during July through September. The study described the most favorable situation for air-mass thunderstorms occurred when moisture from the Gulf of Mexico is transported into the area on southeast winds. In an earlier study, Armstrong (1944) noted that southwest winds over the area in the summer are occasionally strong enough to import moist Pacific air that fuels frequent thunderstorms. Anderson (1959) remarked on the difficulty in predicting summertime thunderstorm movement. Later, in the Terminal Forecast Reference Notebook (1974) for Nellis AFB, it was stated that winds at 14,000 to 16,000 feet MSL determine the direction of movement of thunderstorms. In recent related work,

Watson, et al. (1992) used CG lightning data to show that upper-air winds are closely related to lightning-strike patterns over the southwestern United States during the summer Monsoon.

1.3 Analysis Procedure. As discussed in Chapter 2, CG lightning-strike and atmospheric sounding data for 1986-91 were used to develop a lightning-strike climatology stratified by 700-mb wind direction categories. The area of analysis in Figure 1 was divided into a grid system of square grid boxes, each box 10 minutes of latitude by 10 minutes of longitude, to provide an effective horizontal resolution of 10 nautical miles for the summarized lightning-strike data. Details of the grid system are given in Chapter 3, along with the methods used to stratify the lightning data by 700-mb wind direction categories. In Chapter 4, the options available in the microcomputer lightning climatology graphics program are discussed, and illustrative examples are used to compare the lightning climatology to known thunderstorm patterns.

1.4 Findings. The lightning climatology appeared consistent with expected diurnal and monthly variations in thunderstorm activity. The diurnal variations of lightning strikes near Nellis AFB agreed closely with known diurnal variations in thunderstorm frequencies. Even secondary daily maximums in average hourly lightning strikes were evident in August to match a secondary maximum in hourly observations of thunderstorms for that month. Likewise, monthly variations in average hourly lightning strikes coincided with changes in monthly thunderstorm frequency; July through September had the highest average hourly lightning strikes, with the maximum in August. Monthly patterns in contour analyses of the average hourly lightning-strike fields closely resembled the patterns in mean thunderstorms shown by Changery (1981). As further illustrated in Chapter 4, the lightning climatology verified known preferred spatial orientations of thunderstorms at certain times based on the 700-mb wind direction.

Chapter 2

DATA AND LIMITATIONS

2.1 Lightning Data. The lightning data used was proprietary CG lightning-strike observations purchased from GeoMet Data Services (GDS), Inc., of Tucson, Ariz. The individual lightning-strike records were stored in AFCCC's relational database (DB2) for easy access. During March through December of 1986-91, nearly 2 million strikes occurred in the area of analysis. The strikes were recorded by direction finders manufactured by

Lightning Location and Protection (LLP), Inc., of Tucson, Ariz. As described by Maier, et al., (1983), the LLP equipment that makes up the National Lightning Detection Network (NLDN) uses triangulation to locate the strikes. Thus, every observation of a CG lightning strike provided by GDS was made by at least two direction finders. Figure 2 shows the NLDN direction finders that GDS operated in or near the area of interest during 1986-91.

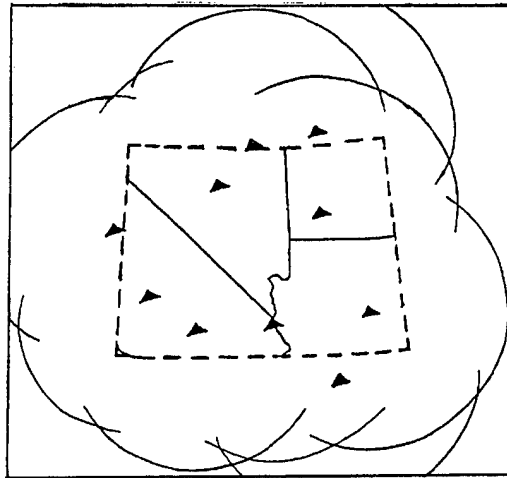


Figure 2. Lightning direction finder locations. Triangles represent approximate locations of NLDN direction finders in and near the area of analysis (dashed lines) during 1986-91. Scalloping around the analysis area shows the nominal range of 215 nautical miles. Source: GDS (personal communication).

2.2 Lightning Data Limitations. Most evaluations of CG lightning-strike data quality include discussions of detection efficiency and strike location accuracy. The period of record is also important for a representative database.

2.2.1 Detection Efficiency. The detection efficiency is the ratio of the number of CG strikes detected to the number that actually occurred. It is primarily a function of the range or the distance of a strike from the direction finders. MacGorman, et al. (1984), reported detection efficiencies of 70 to 85 percent for strikes within 54 nautical miles of direction finder networks in Oklahoma and Florida. Over the NLDN, a detection efficiency of 70 percent is estimated for strikes within a 215-nautical mile range of direction finders (Orville, et al., 1990). Beyond that nominal range, strikes are still detected, but at less efficiency.

For the present work, Figure 2 shows that during 1986-91 most of the area of interest was well within the nominal range for a 70-percent lightning detection efficiency.

2.2.2 Location Accuracy. Like detection efficiency, the strike location accuracy depends on the range of the strike; but it also depends on the number of direction finders that record the strike, the distance between direction finders, and where the strike occurs in relation to the direction finders (Maier, et al., 1983). According to GDS, the lightning strike locations are generally accurate to within 1/2 to 2 nautical miles.

2.2.3 Period of Record. As previously stated, the period of record for the CG lightning-strike data was 6 years for the area of analysis in Figure 1. In a recent study that compared CG lightning strikes to thunder

CHAPTER 2

events, Changnon (1993) showed that due to the high interannual variability in lightning strikes, a short period of record may not be representative of longer-term conditions. For that reason, the average hourly lightning-strike values presented in this work are considered marginally representative as compared to values that could be obtained from a longer period of record. Orville (1991) suggested that at least 10 years of lightning-strike data may be necessary to produce a truly representative climatology.

2.3 Upper-Air Data. Atmospheric soundings from AFCCC's DATSAV Upper-Air database, described in USAFETAC DATSAV Data Base Handbook (1977), were used to obtain 700-mb wind data. Three upper-air sites within the area of analysis were selected for March through December from 1986-91: Desert Rock and Ely in Nev., and San Diego, Calif. (see Figure 1). As described in Chapter 3, data from the

three northernmost upper-air sites were used for the northern part of the analysis area, and data from the others were used for the southern part.

2.4 Upper-Air Data Limitations. Upper-air observations were available only twice daily at 0000Z (1600 Pacific Standard Time (PST)) and 1200Z (0400PST). No attempt was made to interpolate upper-air variables from other hours of the day to those times. As described in Chapter 3, it was assumed that the upper-air data for 0000Z was valid for lightning strikes that occurred from 1800Z to 0559Z. Similarly, upper-air data for 1200Z was assumed valid for strikes that occurred from 0600Z to 1759Z. Obviously, those assumptions ignore upper-air changes between soundings, but the changes are usually considered small. The data used in this work was decoded and validated for data elements, but no further quality control was done.

Chapter 3

METHODOLOGY

3.1 Lightning Data Preparation. A total of 1,771,486 CG lightning-strike observations that occurred during 1986-91 in March through December were extracted from the relational database for the area of analysis in Figure 1. Each lightning observation contained the year, month, day, hour, minute, and latitude and longitude in decimal degrees. The dataset of lightning observations was sorted by year, month, day, and hour for merger with the upper-air data. After sorting, any particular hour included lightning strikes that occurred on that hour and during the 59 minutes after that hour. For example, lightning strikes for 1800Z included all that occurred from 1800Z to 1859Z.

3.2 Upper-air Data Preparation. The 700-mb wind direction and speed for Desert Rock and Ely in Nevada, and San Diego in California were considered correlated so that data from any of the three was representative for the area of analysis. Using three upper-air reporting stations for the area of analysis minimized the number of times with missing 700-mb wind data. Desert Rock had first priority, followed by Ely and San Diego. If data was available for Desert Rock, it was used first. If not, data for Ely was used. If Ely data was missing, data for San Diego was used. The 700-mb wind direction and speed in knots for 0000Z (1600PST) and 1200Z (0400PST) were extracted from the three locations for March through December from 1986-91. The dataset contained 99 percent (1,451 of 1,470) of possible observations (1,382 from Desert Rock; 55 from Ely; and 14 from San Diego). The upper-air datasets were sorted by year, month, day, and hour for merger with the lightning dataset.

3.3 Wind Stratified Lightning Dataset. To stratify the lightning climatology by 700-mb wind direction categories, the datasets of lightning and upper-air observations were merged based on the following conditions:

- Lightning observations that occurred in the area of analysis from 0600Z to 1759Z were matched with the 1200Z upper-air observations.

- Lightning observations that occurred in the area of analysis from 1800Z the previous day to 0559Z were matched with the 0000Z upper-air observations.

After merging the datasets, every lightning observation over the area of analysis contained a 700-mb wind direction and speed, including missing values. Those lightning observations that contained missing wind direction and speed were deleted, since a wind direction category could not be assigned. The effect on the original number of lightning-strike observations was minimal, because only about one percent of the observations were deleted.

3.3.1 Wind Direction Categories. The 700-mb wind direction and speed in each lightning-strike observation was used to assign one of nine wind direction categories to each observation. The first category, C (calm), was assigned to an observation if the wind speed was less than 5 knots regardless of wind direction. The other eight categories: N (north); NE (northeast); E (east); SE (southeast); S (south); SW (southwest); W (west); and NW (northwest) were assigned if the speed was equal to or greater than 5 knots, and the direction was within the following ranges:

N direction between 340° and 360° or direction between 000° and 020°

NE direction equal to or greater than 021° but less than 070°

E direction equal to or greater than 070° but less than 115°

SE direction equal to or greater than 115° but less than 160°

S direction equal to or greater than 160° but less than 205°

SW direction equal to or greater than 205° but less than 250°

CHAPTER 3

W direction equal to or greater than 250° but less than 295°

NW direction equal to or greater than 295° but less than 340°

3.4 Wind Frequency Distribution Dataset. The upper-air data for Desert Rock from 1986-91 was used separately to produce frequency distributions by month and hour for the nine 700-mb wind direction categories. Every 0000Z and 1200Z upper-air observation with reported 700-mb wind direction and speed was used to determine the category. Next, the 6-year total and annual average were calculated for each category by month and hour. Then the 6-year total was calculated for all nine categories by month and hour. The percent occurrence frequency (POF) for each category by month and hour was calculated as follows:

$$\text{POF} = \frac{\text{6-year total each category}}{\text{total all categories}} \quad (1)$$

A dataset was built that contained the annual average number of occurrences and POF for each wind category by month for either 0000Z or 1200Z. It was used to display frequency distribution charts in the lightning graphics described in Chapter 4.

3.5 The Grid System. To prepare the wind stratified lightning dataset for summarization at a horizontal resolution of approximately 10 nautical miles, the area of analysis in Figure 1 was divided into a grid system with the grid point spacing set at 10 minutes of latitude and 10 minutes of longitude. As a result, the grid system contained an array of 1,870 grid points (55 in the east-west direction by 34 in the north-south direction) and 1,782 individual grid boxes. A partial sketch of the grid system is shown in Figure 3 for reference. To simplify analysis, the grid boxes were assumed square. Actually, the distances between degrees of latitude on the earth vary slightly from pole to equator, while the distances between degrees of longitude increase from pole to equator. Therefore, the real areas enclosed by grid boxes are not square and increase from north to south. For the Nellis AFB area, the distance between degrees of latitude from north to south varies little at nearly 60 nautical miles. The distance between degrees of longitude from north to south increases from about 46 nautical miles per

degree at 39°N to about 50 nautical miles per degree at 34°N . As a result, the overall horizontal resolution for lightning-strike analysis is 10 nautical miles. It varies from about 9 nautical miles at the higher latitude to about 10 nautical miles at the lower latitude. Due to the variable resolution, a bias exists for higher counts of lightning strikes in grid boxes at lower latitudes. However, for purposes of this analysis the bias is considered minor.

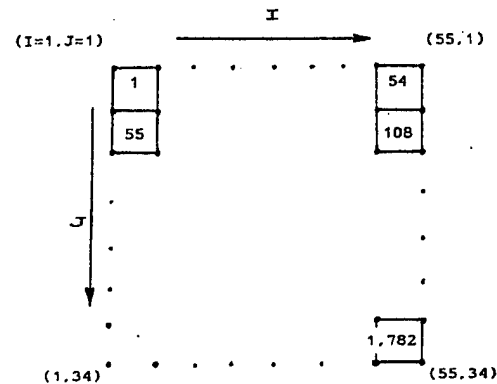


Figure 3. Sketch of the grid system.

3.6 Gridding the Data. To obtain values for the total strikes in individual grid boxes, a grid box number was calculated and assigned to each lightning observation by first converting the latitude and longitude of the strike from degrees to minutes. From procedures given in Hoke, et al. (1985), the following equations were used to calculate the grid-point Cartesian coordinates (x,y) for each lightning observation:

$$x = ((\text{LONI} - \text{LONMIN})/\text{MIN}) + 1 \quad (2)$$

$$y = ((\text{LATI} - \text{LATMIN})/\text{MIN}) + 1 \quad (3)$$

LATMIN = latitude of lightning strike in minutes

LONMIN = longitude of lightning strike in minutes

LATI = latitude in minutes at upper-left corner of grid system

LONI = longitude in minutes at upper-left corner of grid system

MIN = grid spacing in minutes of latitude or longitude

Next, grid-point indexes (I,J) were defined as follows:

$$I = \text{INT}(x) \quad (4)$$

$$J = \text{INT}(y) \quad (5)$$

where the operator INT acts to keep only the whole part of the numbers for x and y. Lastly, the grid box number (BOXNUM) for each lightning observation was calculated from the following:

$$\text{BOXNUM} = I + (\text{SIDEBOX}(J-1)) \quad (6)$$

where SIDEBOX is the number of grid boxes in the east-west direction (54 in this work). As an example, referring to Figure 1, the upper-left corner of the area of analysis is located at 39° 34'N/119° 32'W. From equations 2 through 5, the values of I and J for that point are both one. From equation 6, the grid box num-

ber for a lightning strike at that point is one. As shown in Figure 3, the index I varies from 1 on the left side of the grid system to 55 on the right side. The index J varies from 1 at the top to 34 at the bottom. The grid box numbers increase from 1 in the upper-left corner to 54 in the upper-right corner, and so on to box number 1,782 in the lower-right corner. Once the above gridding procedure was complete, every lightning-strike observation had a grid box number for identification.

3.7 Lightning Data Summarization. The dataset of lightning stratified by 700-mb wind direction categories was summarized to obtain the average number of strikes for each grid box by month, hour, and wind direction category. As a result, each grid box in the area of analysis had a wind stratified lightning-strike climatology for use in the graphics program discussed in the next chapter.

Chapter 4

LIGHTNING CLIMATOLOGY AND RESULTS

4.1 The Lightning Graphics Program. A microcomputer graphics program was written by Pena and Weston (1993) to display the Nellis AFB lightning climatology. The minimum requirements to run the program are: IBM or IBM-compatible 286-based personal computers; 640 KB main memory; MS-DOS Version 3.2 or later; EGA or better graphics; Epson-compatible dot matrix printer for hard copies; and about 8 MB hard-drive space. The program is not validated to operate under Microsoft Windows, and it will not run from floppy drives. A math coprocessor decreases run time but is not required.

4.1.1 Program Particulars. Before describing the graphics displays, a few particulars about the program follow:

- For consistency, average hourly CG lightning-strike values are displayed throughout the program. If several months and (or) hours are selected for a display, the average hourly values collected by the program are divided by the number of months and hours, so that the displayed values are always hourly averages.
- The program uses the average hourly lightning-strike value for a grid box at a grid point defined by the upper-left corner of the grid box.
- If several grid boxes are selected for a graph or table, the value displayed is the sum of the average hourly values for the grid boxes. Thus, area averages are displayed.
- In contrast to graph and table displays, isopleth analyses display contours of the average hourly lightning strikes are based on each grid point (grid box) value.
- All hours are shown in Zulu (Greenwich Mean Time). To obtain Pacific Standard Time (PST), subtract 8 hours from Zulu.

4.1.2. Graphics Displays. The lightning graphics program uses the wind stratified lightning-strike climatology and 700-mb wind direction climatology to present several displays. The displays and output

options include bar graphs, tables, and isopleth analyses as listed below:

- Bar graphs of the variations of average hourly lightning strikes by 700-mb wind direction categories (Calm, N, NE, E, SE, S, SW, W, and NW).
 - One, several, or all grid boxes; months (Mar-Dec); and hours (0000Z-2300Z) may be selected.
- Bar graphs of the daily (diurnal) variations of the average hourly lightning strikes by hour (0000Z through 2300Z).
 - One, several, or all grid boxes; months; and 700-mb wind direction categories may be selected.
- Bar graphs of the annual average number and percent occurrence frequencies of 700-mb wind direction categories for the entire area (based on Desert Rock, Nev. data) for either 0000Z or 1200Z.
 - One, several, or all months may be selected.
- Tables of the average hourly lightning strikes for each 700-mb wind direction category and all categories; and for each month and all months.
 - One, several, or all grid boxes and hours may be selected.
- Isopleth analyses of the average hourly lightning strikes over the entire area.
 - One, several, or all months, hours, and 700-mb wind direction categories may be selected.

4.2 Example of Diurnal Lightning-Strike Variations. To illustrate diurnal variations in lightning strikes around Holloman AFB, the month of August was chosen since it has the highest frequency of thunderstorms as shown in the Surface Observation Climatic Summaries (SOCS) for Nellis AFB, Nev. (1992). An area centered on Nellis AFB, consisting of six grid boxes on each side and about 3,600 square nautical miles, was used to obtain the graph shown in

CHAPTER 4

Figure 4 for all 700-mb wind direction categories. Figure 4 shows that most strikes occur primarily between 1800Z (1000PST) and 0400Z (2000 PST), with a secondary period between 0500Z (2100 PST) and 1500Z (0700 PST). The highest average value of lightning strikes (about 375) at 0000Z (1600 PST) and 0100Z (1700 PST), as well as the secondary

maximum value of about 125 strikes at 1000Z (0200 PST), agree closely with the SOCS for Nellis AFB (1992) which shows two peaks in thunderstorm frequency as reported on hourly observations at Nellis AFB during August. The primary peak occurs from 1800 PST to 2000 PST, and the secondary peak from 0300 PST to 0500 PST.

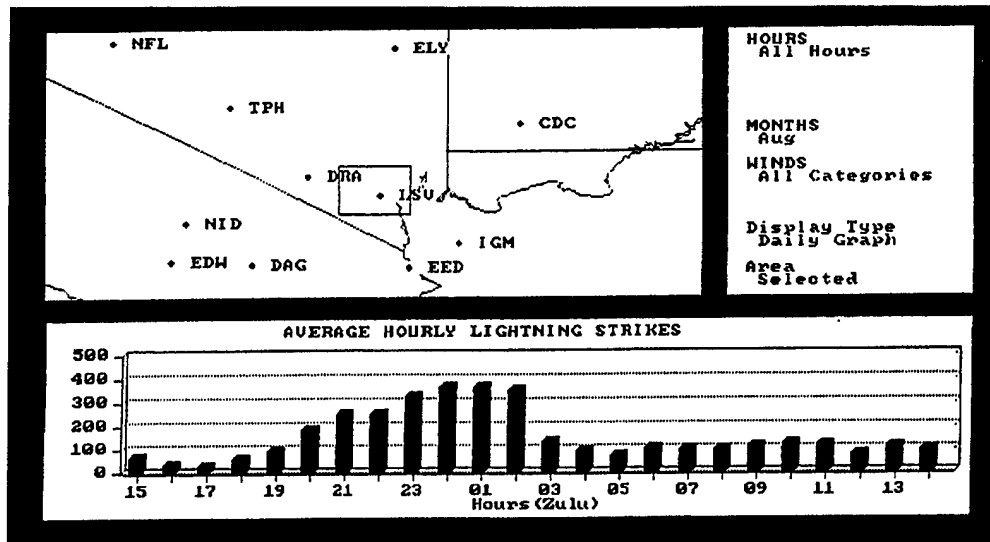


Figure 4. Diurnal variations in lightning strikes around Nellis AFB, Nev. during August. Graph shows average hourly lightning strikes for all 700-mb wind directions within an area of about 3,600 square nautical miles centered on Nellis AFB (LSV).

4.3 Monthly Lightning-Strike Variations. It is well known that most thunderstorms occur over the Southwestern United States during the summer months of July, August, and September. The SOCS for Nellis AFB, (1992) shows that for all hours and all months, the frequency of thunderstorms based on hourly observations increases to a maximum in August with the highest frequency in July through September. A similar trend occurs in the monthly variations of average hourly lightning strikes. To illustrate this,

the same area around Nellis AFB was used as in Figure 4 to obtain a table of average hourly lightning strikes by 700-mb wind directions for all hours. As seen in Table 1, the months of July through September have the highest average hourly lightning strikes based on all 700-mb wind direction categories, with the maximum in August. The table also shows a predominance of strikes when the 700-mb winds are from the south and southwest, especially during the summer.

Table 1. Monthly variations in average hourly lightning strikes by 700-mb wind directions for all hours around Nellis AFB. Area of analysis is the same as in Figure 4.

700-mb Wind Direction										
For 0-23 Hours Zulu										
CALM	N	NE	E	SE	S	SW	W	NW	ALL	
MAR	0	0	0	0	0	0	1	0	0	1
APR	0	0	3	0	2	3	1	1	0	10
MAY	0	0	0	3	1	2	4	4	2	16
JUN	0	0	0	1	6	6	7	1	0	21
JUL	4	1	0	11	2	32	12	3	32	97
AUG	0	4	0	18	7	62	55	4	2	152
SEP	3	1	5	4	7	12	20	4	3	59
OCT	0	0	0	0	1	3	0	1	0	5
NOV	0	0	0	0	5	1	0	0	0	6
DEC	0	0	0	0	0	0	0	0	0	0
ALL	7	6	8	37	31	121	100	18	39	367

4.4 Wind Stratified Lightning Climatology
Example. The month of August was chosen again to illustrate the wind stratified lightning-strike climatology in the 3,600-square-nautical-mile area around Nellis AFB. The period from 1800Z (1000 PST) to 0400Z (2000 PST) shown in Figure 4 was used to determine which 700-mb wind direction was

associated with most of the strikes during that time. As shown in Figure 5, the 700-mb winds were mostly from the south when the highest value of average hourly lightning strikes occurred. This is also evident from the frequency distribution graphs of 700-mb wind direction categories for August shown in Figure 6.

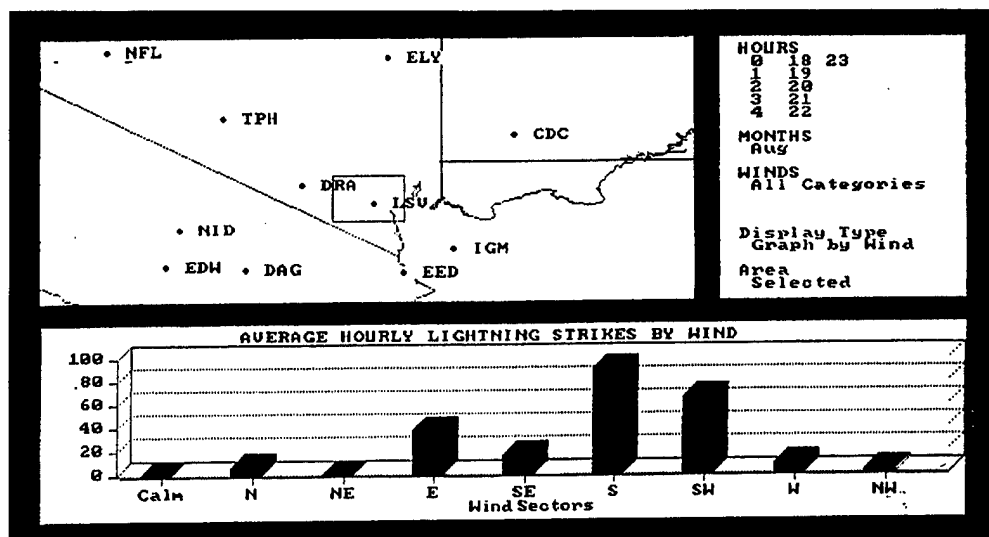


Figure 5. Variations in average hourly lightning strikes by 700-mb wind direction from 1800Z (1000PST) to 0400Z (2000PST) during August around Nellis AFB, Nev. Area of analysis is the same as in Figure 4.

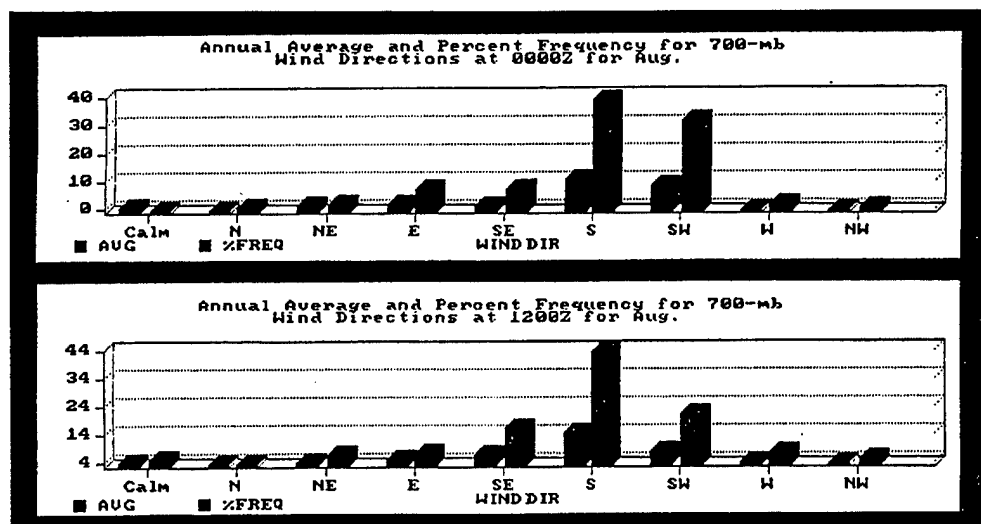


Figure 6. Frequency distributions of 700-mb wind directions for 0000Z (1600PST) and 1200Z (0400PST) during August in the Nellis AFB Area. Based on data from Desert Rock, Nev.

4.5 Regional Lightning-Strike Patterns. Isopleth analyses of the average hourly lightning strikes were examined to compare lightning-strike patterns to known thunderstorm patterns. A local Forecast Study (1954) noted that a favorable summertime situation for thunderstorms occurred when moisture from the Gulf of Mexico was pulled into the Nellis AFB area on southeast winds. Assuming first that the southeast winds mentioned were low-level winds, and second that warm air advection was occurring in the lower troposphere, it is thus assumed that the 700-mb winds were south or southwest. An example of this favorable thunderstorm situation was selected from August, when 700-mb winds are predominantly from the south, around the time of maximum lightning strikes near Nellis AFB. In Figure 7 for August at 0000Z (1600 PST) with 700-mb winds from the south, the contours show an area of lightning strikes to the east of Nellis AFB over the Muddy Mountains. An hour later at 0100Z (1700 PST), as shown in Figure 8, areas of lightning strikes appear over the other mountains to the west, northwest, and north. By 0200Z (1800 PST), Figure 9 shows that lightning strikes occur at Nellis AFB in the valley. The lightning-strike pattern was gone by 0300Z (not shown). An interesting example of a lightning-strike area changing position, apparently in part due to the 700-mb wind direction,

is shown in the next four figures. Inspection of the wind stratified graph for July around Nellis AFB showed that most of the lightning strikes during the period from 0000Z (1600 PST) to 0900Z (0100 PST) are associated with 700-mb winds from the northwest. With that as a basis, consider Figure 10 for July at 0200Z (1800 PST) with 700-mb winds from the northwest. The contours show a large area of lightning strikes about 50 nautical miles north through northeast of Nellis AFB. By 0300Z (1900 PST), as shown in Figure 11, the area of strikes appears to have moved south, and the northeastern part of Nellis AFB is affected. At the next hour (Figure 12), the area of lightning strikes is over Nellis AFB. Finally at 0500Z (2100 PST), as seen in Figure 13, the area of strikes is southeast of Nellis AFB. As a last example to show similarities between patterns in thunderstorm climatology and this lightning-strike climatology, refer to Figures 14 and 15. Figure 14 from Changery (1981) shows the mean number of thunderstorms over the Southwestern United States during August. By comparison, Figure 15 shows contours of the average hourly lightning strikes in the Nellis AFB analysis area for August for all hours and 700-mb wind directions. It can readily be seen that the lightning-strike pattern closely resembles the thunderstorm pattern.

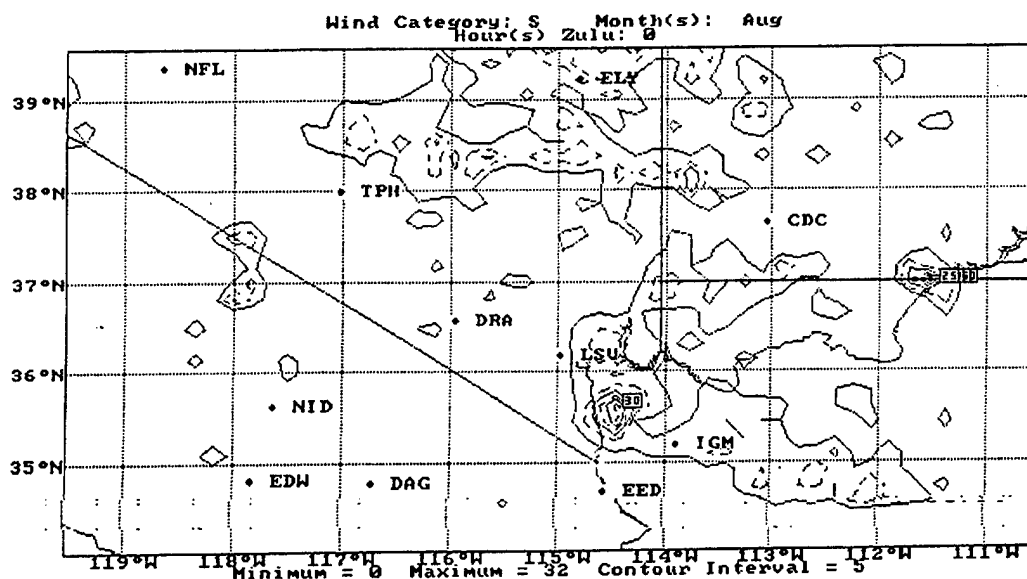


Figure 7. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the south at 0000Z (1600PST) in August. Area of analysis is the same as in Figure 1.

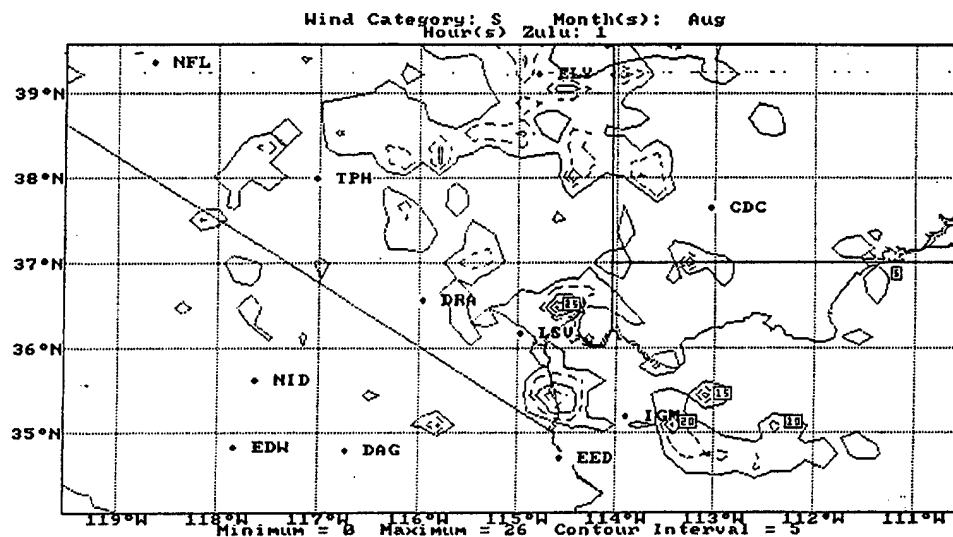


Figure 8. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the south at 0100Z (1700PST) in August. Area of analysis is the same as in Figure 1.

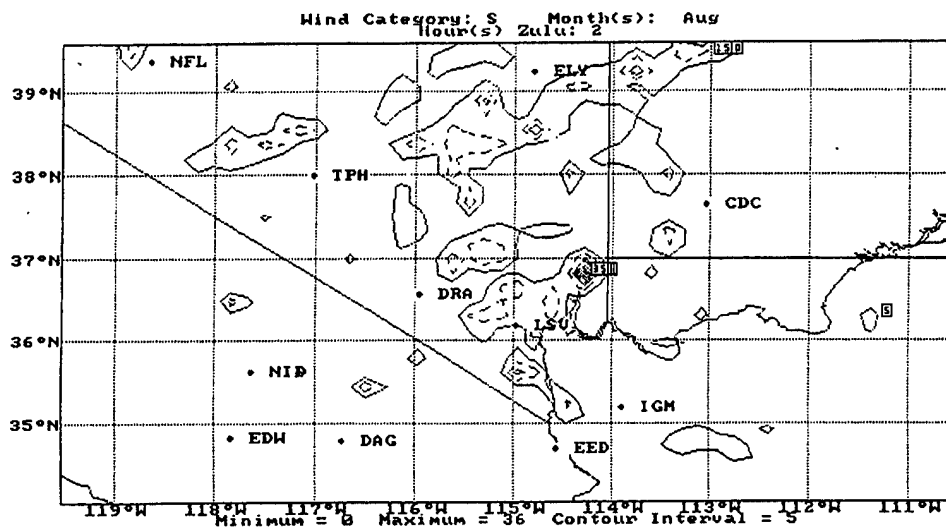


Figure 9. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the south at 0200Z (1800PST) in August. Area of analysis is the same as in Figure 1.

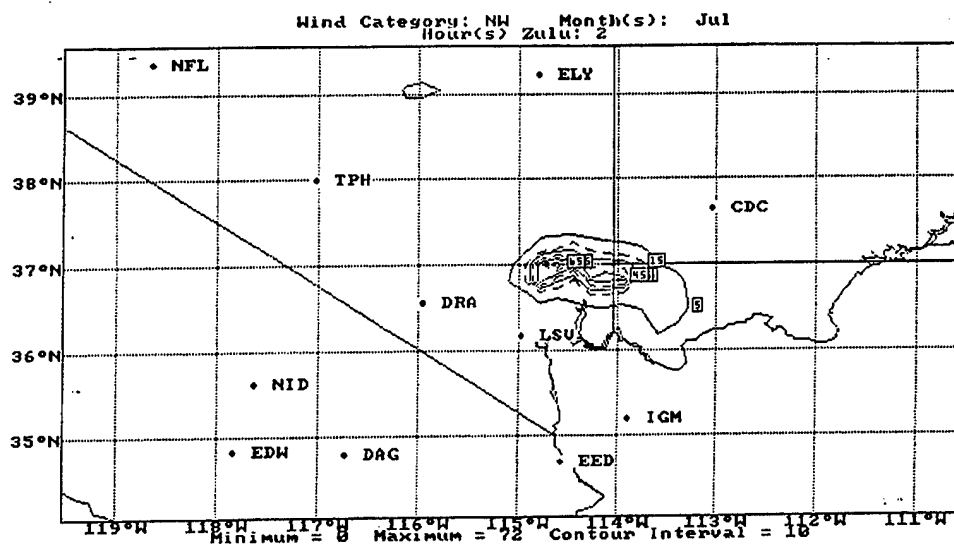


Figure 10. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the northwest at 0200Z (1800PST) in July. Area of analysis is same as in Figure 1.

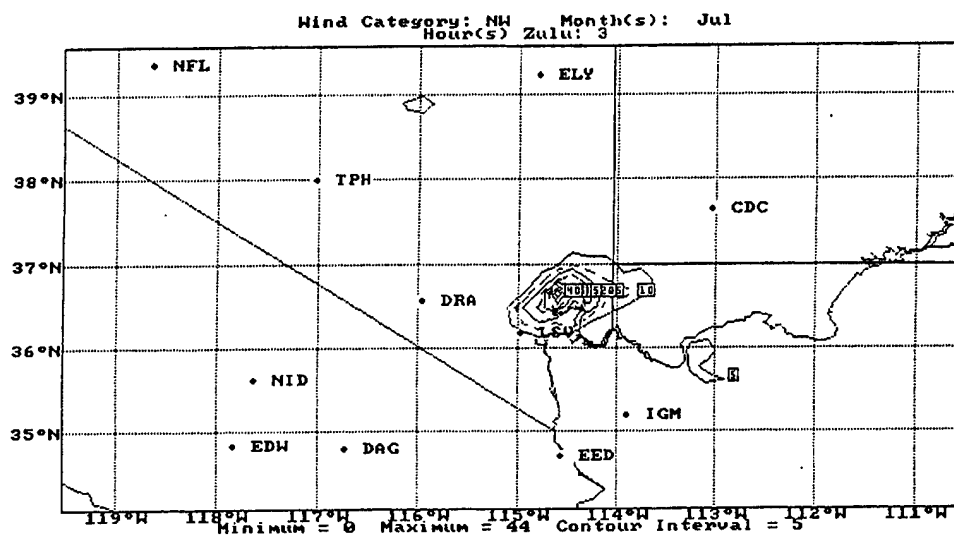


Figure 11. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the northwest at 0300Z (1900PST) in July. Area of analysis is same as in Figure 1.

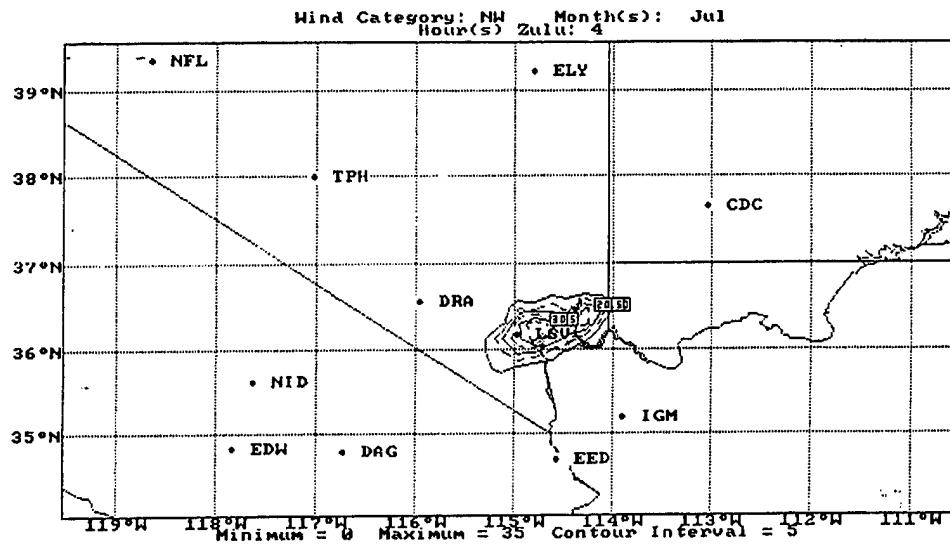


Figure 12. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the northwest at 0400Z (2000PST) in July. Area of analysis is same as in Figure 1.

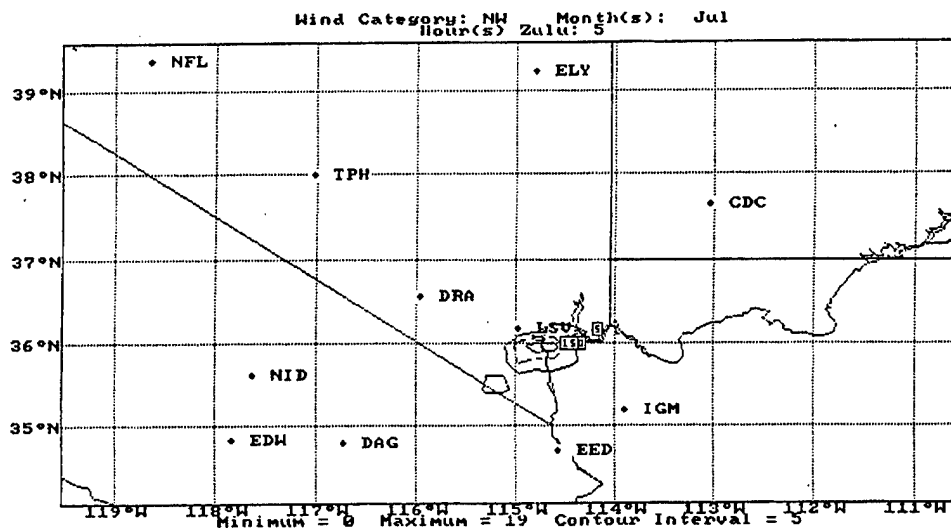


Figure 13. Isopleth analysis of the average hourly lightning strikes with 700-mb winds from the northwest at 0500Z (2100PST) in July. Area of analysis is same as in Figure 1.

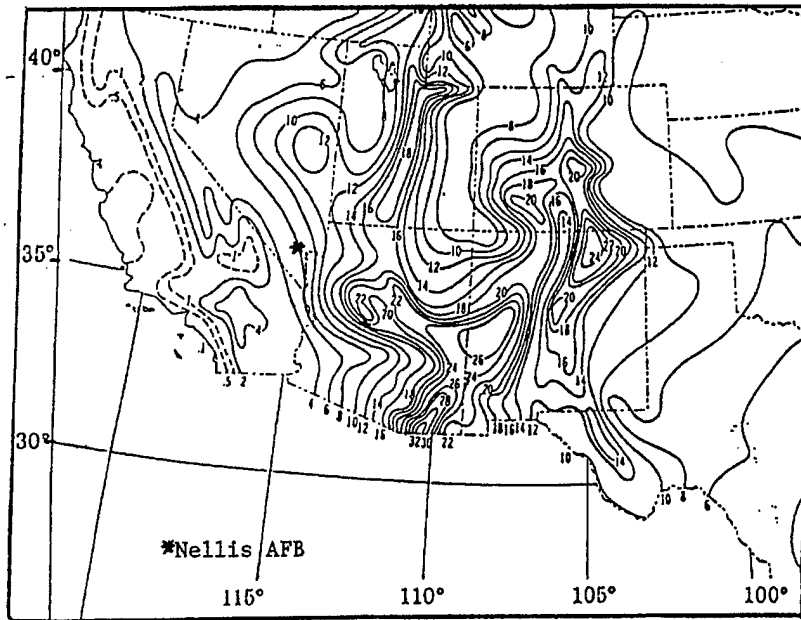


Figure 14. Analysis of the mean number of thunderstorms during August over the southwestern United States. Adapted from Changery (1981).

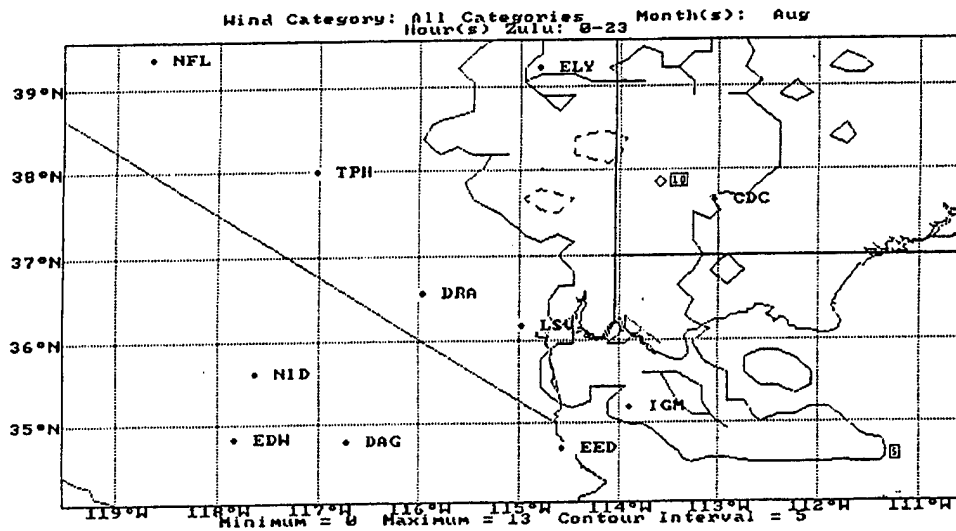


Figure 15. Isopleth analysis of the average hourly lightning strikes for all 700-mb wind directions and all hours during August. Area of analysis is as in Figure 1.

Chapter 5

Summary

5.1 Discussion. The CG lightning-strike climatology stratified by 700-mb wind directions was developed to help weather forecasters more accurately predict thunderstorms in the vicinity of Nellis AFB, Nevada. Despite limitations in the lightning-strike and upper-air data used, it was shown by comparison to known temporal and spatial variations in summertime thunderstorms that the lightning-strike climatology adequately depicts several of the variations. The wind stratification appeared effective at showing preferred lightning-strike locations and movement based on the

700-mb wind direction. Undoubtedly, the lightning-strike climatology holds much more information about lightning-strike patterns than what was presented in this report.

5.2 Recommendation. AFCCC recommends use of lightning climatology as another tool to predict thunderstorms at Nellis AFB. When used in combination with analyses of the synoptic situation, the lightning climatology has potential to improve thunderstorm forecasts.

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GLOSSARY

AFB	Air Force Base
AFCCC	Air Force Combat Climatology Center (formerly USAFETAC)
BOXNUM	Grid box number
C	Calm
CG	Cloud-to-ground (lightning)
DATSAV	AFCCC's database of surface and upper-air data
DB2	AFCCC's relational database
E	East
EGA	Enhanced Graphics Adapters
GDS	GeoMet Data Services, Inc.
I	Grid-point index
IBM	International Business Machines Corp.
INT	Operator that acts to keep only the whole part of a number
J	Grid-point index
KB	Kilobyte
LATl	Latitude in minutes at upper-left corner of grid system
LATM I N	Latitude of lightning strike in minutes
LLP	Lightning Location and Protection, Inc.
LONl	Longitude in minutes at upper-left corner of grid system
LONMIN	Longitude of lightning strike in minutes
mb	Millibar(s)
MB	Megabyte
MIN	Grid spacing in minutes of latitude or longitude
MS-DOS	Microsoft-Disk Operating System
N	North
NE	Northeast
NLDN	National Lightning Detection Network
NW	Northwest
POF	Percent occurrence frequency
PST	Pacific Standard Time
S	South
SE	Southeast
SIDEBOX	Number of grid boxes in east-west direction
SOCS	Surface Observation Climatic Summaries
SW	Southwest
USAFETAC	United States Environmental Technical Applications Center (renamed AFCCC)
W	West
x	Grid-point Cartesian coordinate
y	Grid-point Cartesian coordinate
Z	Zulu (Greenwich Mean Time)